行政院國家科學委員會補助專題研究計畫 □ 成果報告 ■期中進度報告

超精密加工鑽石膜技術之研發及其加工表面之性狀分析(1/2)

計畫類別：■ 個別型計畫　　□ 整合型計畫
計畫編號：NSC91-2212-E-032-005
執行期間： 91 年 08 月 01 日至 92 年 07 月 31 日

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計畫參與人員：

成果報告類型(依經費核定清單規定繳交)：■精簡報告　□完整報告

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中　華　民　國　九　十　一　年　五　月　日

行政院國家科學委員會專題研究計畫成果報告

超精密加工鑽石膜技術之研發及其加工表面之性狀分析(1/2)

A Study of Precision Machining of the CVD Diamond Film and Integrity of the Machined Surface

計畫編號：NSC 91-2212-E-032-005
執行期限：91 年 8 月 1 日至 92 年 7 月 31 日
主持人：趙崇禮　　淡江大學機械工程學系

1.中文摘要

由於通訊、光電等產業之快速發展表面聲波元件(SAW-Surface Acoustic Wave Devices) 如SAW-Resonator、SAW-Duplexer及SAW-Sensors等，需求量大增。但目前國內SAW元件之製造廠商主要為替國外大廠封裝代工或生產技術層次較低之中低頻濾波器濾波器，市場佔有率極低(<5%) ；亟待國內產官學積極參與開發。

通常SAW元件多使用鈮酸鋰($LiNbO_3$), 鉭酸鋰 ($LiTaO_3$)及石英(Quartz) 等晶體做基板而其表面聲波速度相對較低。隨無線通訊之進步其頻率亦不斷的提高，濾波晶片上微電極（IDT, Interdigital Transducer）的最小線寬要求也隨之縮小。以高表面聲速之材料座基板對超高頻表面聲波元件之實踐應是必然的趨勢。因Diamond之表面聲波速度極高(約可達到10000m/s)所以國外研究正積極試圖研發出ZnO/Diamond層狀結構之表面聲波元件。總觀未來市場需求及各表面聲波材料之各項特性鑽石薄膜應確定是明日之星；這也是為何各先進國家斥重資積極研發的原因。

本研究計畫將以微波電漿生長法在矽單晶上沈積鑽石薄膜，以高溫機化學研磨、鑽石粉末拋光與雷射剝蝕對鑽石薄膜進行加工；並探討加工之各項參數對加工表面造成之影響及其主要之材料去除機制、加工表面與次表面之顯微組織變化及其與加工參數間之關係。

關鍵詞：超精密加工，表面聲波元件、鑽石薄膜、精密拋光、雷射剝蝕

Abstract

Owing to the rapid development in the mobile telecommunication and optoelectronic area, SAW-(Surface Acoustic Wave) devices such as SAW-Resonator、 SAW-Duplexer and SAW-Sensors are in great demand. However, the domestic SAW-related manufacturers are mainly producing relatively low-level SAW filters for the major players abroad. Further SAW-related researches and investigations are desperately needed if Taiwan is going to play a role in the SAW-related industries.

Crystals such as $LiNbO_3$, $LiTaO_3$, and Quartz are frequently used as the substrate material for SAW devices. However, the surface acoustic wave velocity obtainable on these materials are relatively low. ZnO/Diamond structure has attracted a lot of attentions and heavy investment recently just because diamond has the capability of producing very high surface acoustic wave (around 10000m/s).

In this research, the microwave chemical vapor deposition method will be employed to produce epitaxial diamond films on silicon single crystal. Systematic precision grinding/ lapping/polishing experiments will then be conducted on the obtained diamond films. The underlying material removal mechanisms, microstructure of the machined surface/ subsurface and how they relate to the machining conditions will be investigated.

Keywords: precision machining, SAW, CVD diamond film, laser ablation

2. Introduction(緣由與目的)

Crystals such as $LiNbO_3$, $LiTaO_3$, and

Quartz are frequently used as the substrate material for SAW devices (Senbo Takashi 2000; Nishizawa Toshio 2000). However, the surface acoustic wave velocity obtainable on these materials is relatively low (2500~4500m/s). The frequency of the device is governed by the equation $F = v / \lambda$, where F is the frequency, v is the velocity of the surface acoustic wave and λ is the wavelength which is determined by the line width of the IDT (Interdigital Transducer). This means that higher frequency can be obtained either by choosing a substrate material with a higher surface acoustic wave velocity or by reducing the line width of the IDT.

Shown in table 1 are the line widths of various substrate materials when a 2.5GHz working frequency is required. It is clear that the required line width is much easier to achieve when diamond is used as substrate material.

Table 1

Substrate Materials	Velocity (m/s)	Freq.	IDT linewidth (μm) @2.5GHz
$LiTaO_3$	3300	800MHz	0.33
$LiNbO_3$	3500	900MHz	0.35
Quartz	3200	800MHz	0.32
ZnO/Glass	3200	800MHz	0.32
ZnO/Sapphire	5500	1.4GHz	0.55
ZnO/Diamond	10000	2.5GHz	1.0

ZnO/Diamond structure has attracted a lot of attentions and heavy investment recently just because diamond has the capability of producing very high surface acoustic wave (around 10000m/s). However, diamond has to be machined to the specified thickness and surface finish before it is to be used as substrate material of a SAW device (Higaki 1997; Kadota & Kitamura 1999). The trouble is that diamond has the highest hardness number of the known materials and is extremely difficult to be machined.

Many researches have been conducted, in the past decades, on machining CVD-diamond film by mechanical grinding/lapping/ polishing (Tokura et al, 1991; Spear & Dismukes 1993; Yoshikawa et al 1990, 1996; Jin et al 1992, 1995), by laser ablation (Tezuka & Yoshikawa 1990; Ravi & Zarifis 1993; Tokarev et al 1995; Chien et al 1995), by ion-beam machining (Funamoto & Koseki 1991; Vivensang et al 1996) or by RIE (reactive ion etching) (Sandhu & Chu). Apart from material removal rate, the underlay physic phenomena involved in those machining techniques were also discussed in these researches. Though some very promising results have been obtained, the problems related to the machining of CVD diamond film are still far from fully resolved.

In the present study, the CVD diamond films were hot-lapped and laser polished to investigate its machinability.

3. Experimental Setup

The microwave CVD method was employed in this study to produce epitaxial diamond films on silicon single crystal. Hot polishing together with laser ablation experiments were then conducted on the obtained diamond films. Shown in Fig.1 is the schematic representation of the setup for hot polishing experiments. The iron bar was heated by either infrared irradiation or inductive heating devices to various skin temperature. The specimen was mounted on a flexure which was then brought to contact with the heated iron bar and the contact force was monitored through the displacement of the flexure.

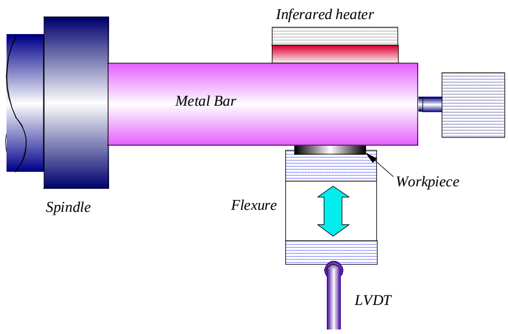

Fig.1 Schematic representation of the setup for hot polishing experiments

The relative speeds of polishing, duration of polishing were also recorded. Some minimeters of the iron bar surface was taken off with a turning tool each time before starting a new set of experiment to ensure the surface conditions maintained as closely the same as possible.

The excimer lasers used in this study were the

Lambda Physik LPX200 series (ArF 193nm) which had a maximum repetition rate of 100 Hz, maximum pulse energy of 400mJ and pulse duration of 20ns. A MicroLas made homogenizer and x10 condenser lens were used to homogenize the beam and increase the fluence respectively. The CVD diamond film, horizontally placed on an XY stage, was irradiated in air by excimer laser (ArF 193nm) at a 90^{o} angle of incidence. The laser spot size was approximately 1.4x1.4mm.

4. Results and Discussions

Shown in Fig.2 was the SEM micrograph of the surface of the as-grown CVD diamond film. The micrograph of the surface of CVD diamond film after irradiated by excimer laser (193nm, 385mJ /10Hz) for 500, 1000, 3000, 5000, 10000 shots were shown in Fig.3 to Fig.7 respectively. It is quite clear that the surface roughness (Ra/Rt) can be improved from 0.17μm/2.8μm of the as grown to around 0.1μm/1μm in 500shots(Fig.8, Fig.9). The peaks of the diamond grains were removed mainly by the photo thermal effects introduced by excimer laser. That is the high energy density and short pulse duration characters of excimer laser play important roles in raising the protruding diamond grains to an evaporating temperature. However, as the protruding peaks gradually removed from the surface the polishing rate decreases.

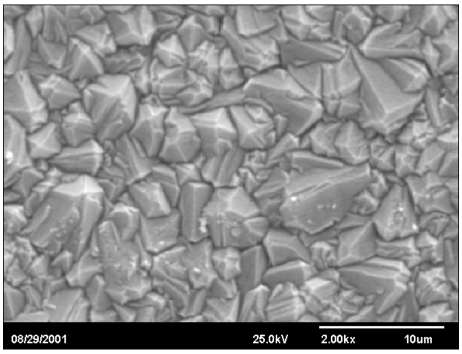

Fig.2 Surface morphology of the as-grown CVD diamond film

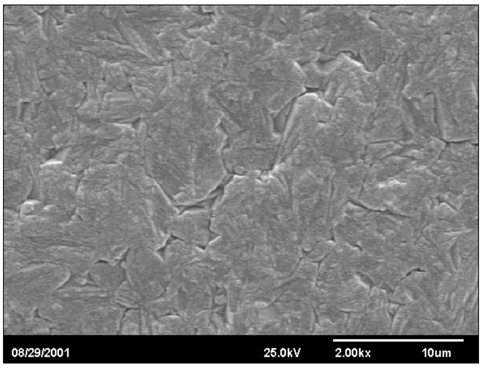

Fig.3 Surface morphology of CVD diamond film after irradiated by excimer laser (193nm, 385mJ /10Hz) for 500 Shots

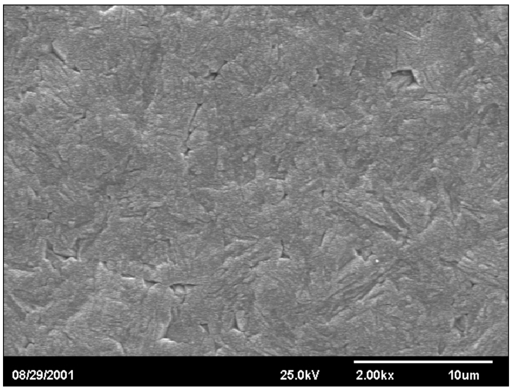

Fig.4 Surface morphology of CVD diamond film after irradiated by excimer laser (193nm, 385mJ /10Hz) for 1000 Shots

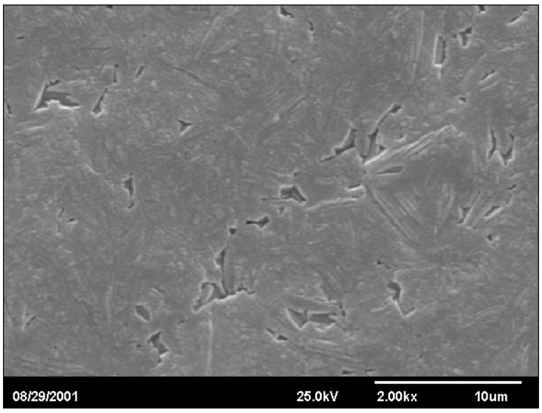

Fig.5 Surface morphology of CVD diamond film after irradiated by excimer laser (193nm, 385mJ /10Hz) for 3000 Shots

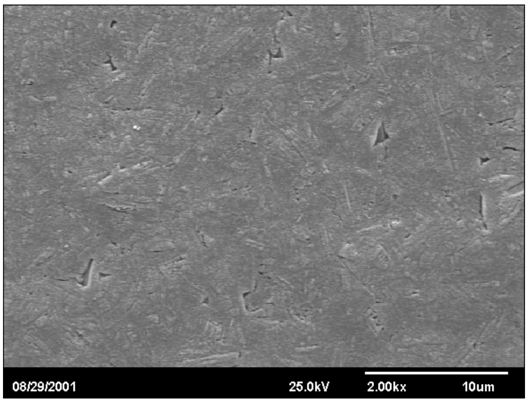

Fig.6 Surface morphology of CVD diamond film after irradiated by excimer laser (193nm, 385mJ /10Hz) for 5000 Shots

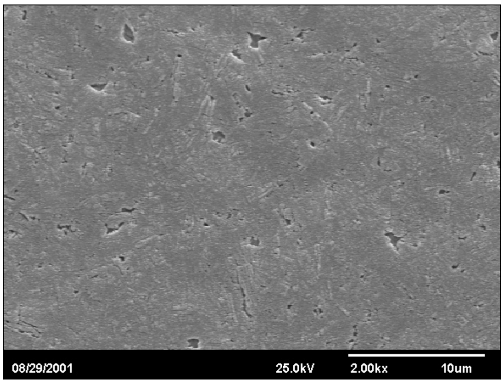

Fig.7 Surface morphology of CVD diamond film after irradiated by excimer laser (193nm, 385mJ /10Hz) for 10000 Shots

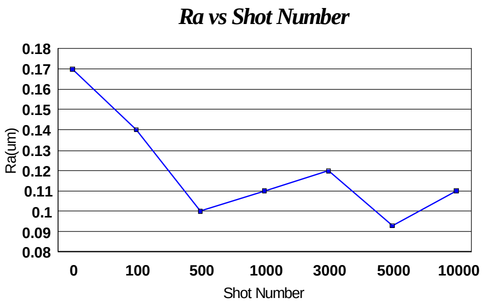

Fig.8 Surface roughness Ra of laser machined CVD diamond film plotted against shot number

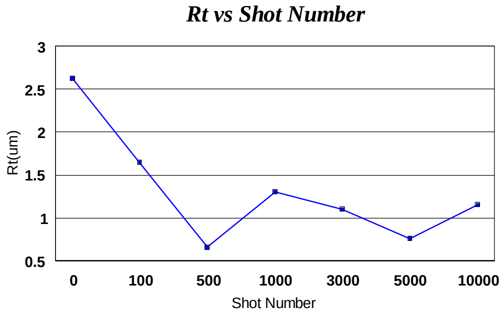

Fig.9 Surface roughness Rt of laser machined CVD diamond film plotted against shot number

Shown in Fig. 10 to Fig. 12 were the SEM micrographs of the CVD diamond film which were hot polished for 10 minutes under various spindle speeds (100rpm, 330rpm and 900rpm) at a temperature around 350°C (skin temperature of the iron bar, measured by an infrared temperature detector, just outside the polishing area). Although a temperature higher than 700°C will be better for chemical reaction, the selected polishing temperature (350°C) is very closed to the limit that can be reached by using the infrared heater available in our laboratory. Based on the obtained results, the heat generated by the friction between iron bar and diamond film has pushed up the temperature at the contact area, and consequently, promoted the needed thermo-chemical effect. Some 1.5μm deep of diamond film was successfully removed in 10 minutes in the case of polishing at 330rpm.

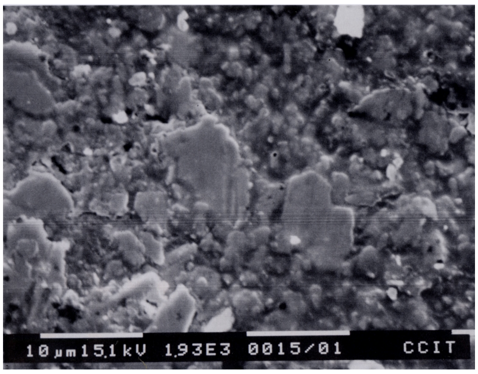

Fig.10, SEM micrographs of the hot polished CVD diamond film (100rpm /10min-0.39m/s)

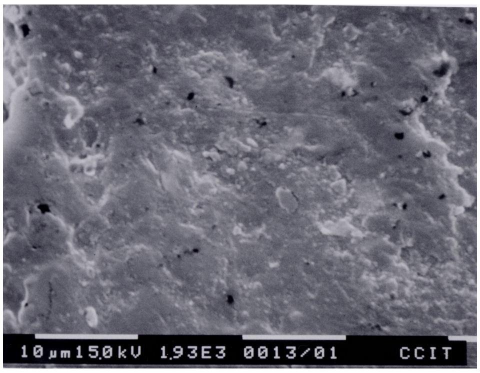

Fig.11, SEM micrographs of the hot polished CVD diamond film (330rpm /10min-1.28m/ s)

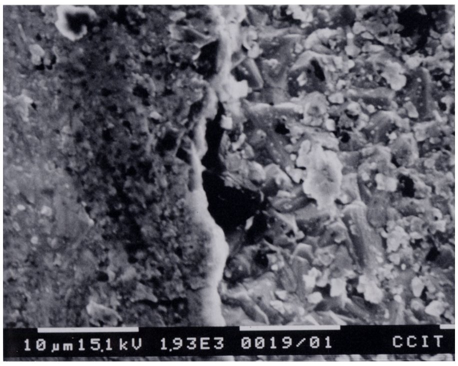

Fig.12, SEM micrographs of the hot polished CVD diamond film (900rpm /10min-3.49m/ s)

5. Conclusions

Thermal-chemical polishing and laser ablation experiments were conducted on the CVD diamond films and results showed that

1. hot polishing was proved to be achievable on a rather simple setup and could remove the diamond film very effectively.
2. laser ablation could improve the surface roughness from above 0.17μm to around 0.1μm in a minute.
3. raster scanning technique would be required if a large area was to be polished by laser and, as a consequence, it could be very time consuming.

6. 計畫成果與自評

1. 瞭解以熱機化學拋光加工鑽石薄膜時其主要之材料去除機制。
2. 探討熱機化學拋光各項加工參數對加工表面造成之影響。
3. 分析準分子雷射加工鑽石薄膜時其主要之材料去除機制。
4. 瞭解加工表面之顯微組織變化與材料去除機制及加工參數間之關係。
5. 分析以準分子雷射對鑽石薄膜進行加工並對加工加工表面/次表面進行分析以建立其與加工參數間之關係。
6. 以高溫之 Fe 合金拋光盤輔以氧或氫氣對鑽石薄膜進行研磨加工；並對加工加工表面/次表面進行分析以建立其與加工參數間之關係。
7. 在鑽石膜生成及加工之各階段以微拉曼光譜分析瞭解其表面特性。

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